National Aeronautics and Space Administration

Airframe Icing

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Technical Challenges

1 **Engine Icing: Characterization and Simulation Capability (FY25):** Develop knowledge bases, analysis methods, and simulation tools needed to address the problem of engine icing; in particular, ice-crystal icing

Goal: *Eliminate turbofan engine interruptions, failures, and damage due to flight in high ice-crystal content clouds*

Benefit: *Verified basis for engine icing certification requirements; enable new engine icing protection systems and methods*

Benefit Domain: *All turbofan/turbojet powered aircraft*

2 **Airframe Icing Simulation and Engineering Tool Capability (FY25):** Develop and demonstrate 3-D capability to simulate and model airframe ice accretion and related aerodynamic performance degradation for current and future aircraft configurations in an expanded icing environment that includes freezing drizzle/rain

Goal: *Achieve acceptance of simulation tools for design and certification of swept wing configurations over an expanded range of icing conditions.*

Benefit: *Enable aircraft manufacturers to perform reliable icing assessments and build in effective icing mitigation approaches for current and future aircraft; development of technology that enables safe flight operations in an super-cooled large droplet environment*

Benefit Domain: *Aircraft and aircraft sub-system manufacturers and aviation system regulators*

3 **Atmospheric Hazard Sensing & Mitigation Technology Development (FY25):** Improve and expand remote sensing and mitigation of hazardous atmospheric environments and phenomena

Goal: *Mature technologies for sensing and measurement of icing, turbulence, and wake vortex hazards for real-time information to the pilot and operators in the NAS and to address low visibility conditions for safer runway operations; develop technologies for a lightning immune composite aircraft.*

Benefit: *Greater ability for aircraft to avoid hazards; hazard information available for sharing with other aircraft and ground-based systems; reduced vulnerability to lightning and other hazards*

Benefit Domain: *All aircraft flying in the NAS*

Technical Challenges

Airframe Icing Simulation and Engineering Tool Capability (FY25): Develop and demonstrate 3-D capability to simulate and model airframe ice accretion and related aerodynamic performance degradation for current and future aircraft configurations in an expanded icing environment that includes freezing drizzle/rain

Goal:
Achieve acceptance of simulation tools for design and certification of swept wing configurations over an expanded range of icing conditions.

Benefit:
Enable aircraft manufacturers to perform reliable icing assessments and build in effective icing mitigation approaches for current and future aircraft; development of technology that enables safe flight operations in an super-cooled large droplet environment

Benefit Domain:
Aircraft and aircraft sub-system manufacturers and aviation system regulators

Atmospheric Environment Safety Technologies Project

Airframe Icing Simulation and Engineering Tool Capability

- Develop and demonstrate 3-D capability to simulate and model airframe ice accretion and related aerodynamic performance degradation for current and future aircraft configurations in an expanded icing environment that includes freezing drizzle/rain.

Two Technology Fronts

1. Current and future aircraft configurations → swept wing.
2. Expanded icing envelope → SLD, freezing drizzle and rain.

Atmospheric Environment Safety Technologies Project

Airframe Icing Simulation and Engineering Tool Capability

Current and Future Airframes (swept-wing)

- Technology Building Blocks:
  1. Computational Ice Accretion Simulation
  2. Experimental Ice Accretion Simulation
  3. Experimental Aerodynamics Simulation
  4. Computational Aerodynamics Simulation
- Each building block has unique objectives and a technology development roadmap.

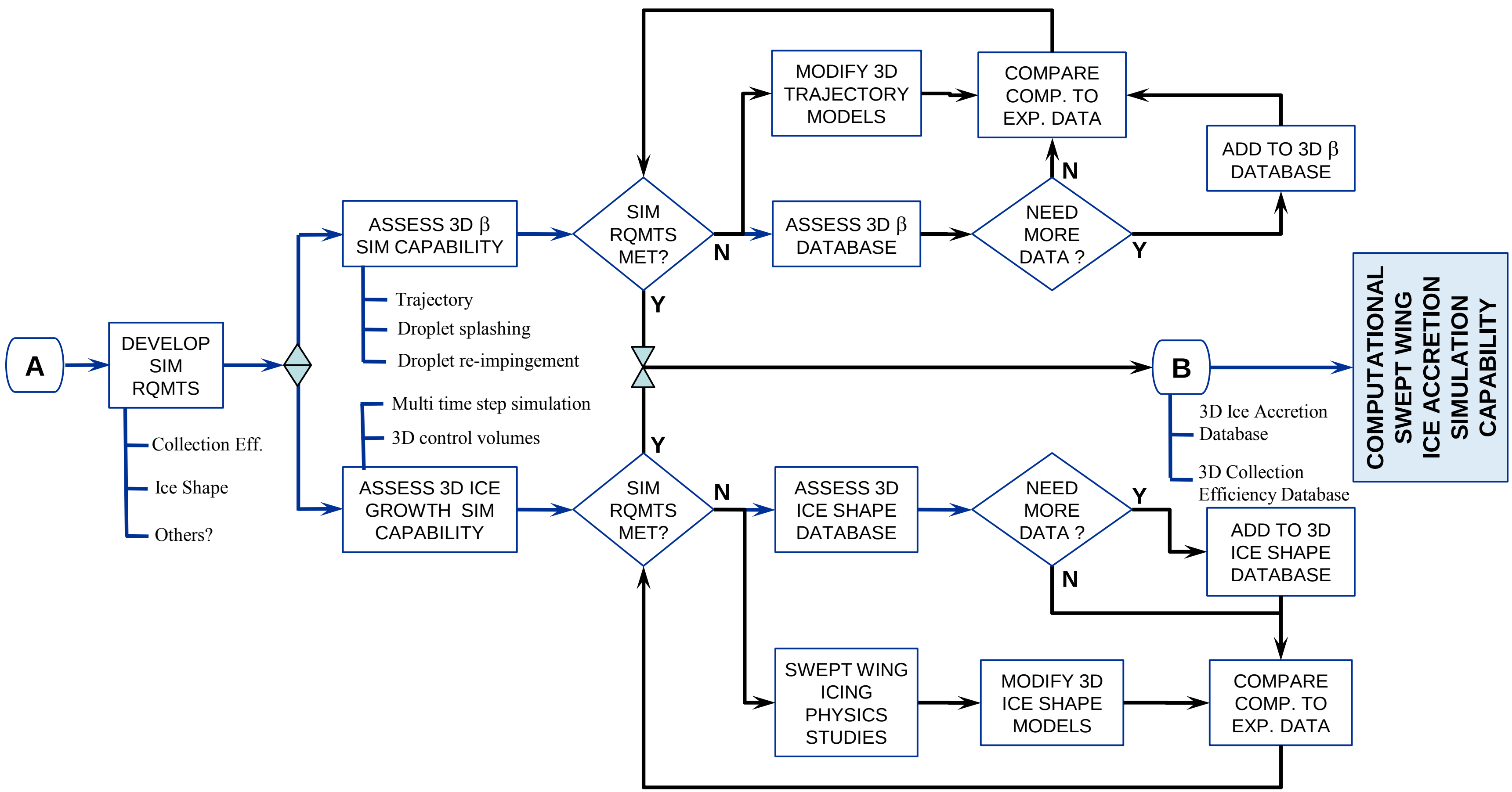
Expanded Icing Envelope (SLD)

- Technology Building Blocks:
  1. Experimental SLD Ice Accretion Simulation
  2. Computational SLD Ice Accretion Simulation
  3. Ice Protection System Modeling for SLD
- Each building block has unique objectives and a technology development roadmap.

Swept Wing Icing Research

Computational Ice Accretion Simulation

Technology Development Roadmap



Computational Ice Accretion Simulation

Objective

Develop and demonstrate computational simulation capability (e.g., codes like LEWICE 3D) for ice build-up on a 3D aircraft surface such as a swept wing.

Research Tasks

- Assessment of Computational Swept Wing Icing Simulation Capability
  - Define simulation requirements
  - Assess 3D collection efficiency capabilities
  - Assess 3D ice shape simulation capabilities
  - Compare capabilities to requirements
  - Develop recommendations for testing and model development
- Swept Wing Icing Physics Studies
  - Develop and implement test programs based upon recommendations from assessment task.
  - Identify existing databases for swept wing ice shapes and collection efficiency
  - Assess need for additional ice shape and collection efficiency data
  - Recommend and develop test program for swept wing ice shapes and collection efficiency data
- Computational Model Development for Swept Wing Icing Simulation
  - From assessment task and icing physics studies, develop new models for swept wing simulation
  - Compare computational results to experimental data
  - Document improvements to ice shape and collection efficiency modeling

Computational Ice Accretion Simulation Milestones

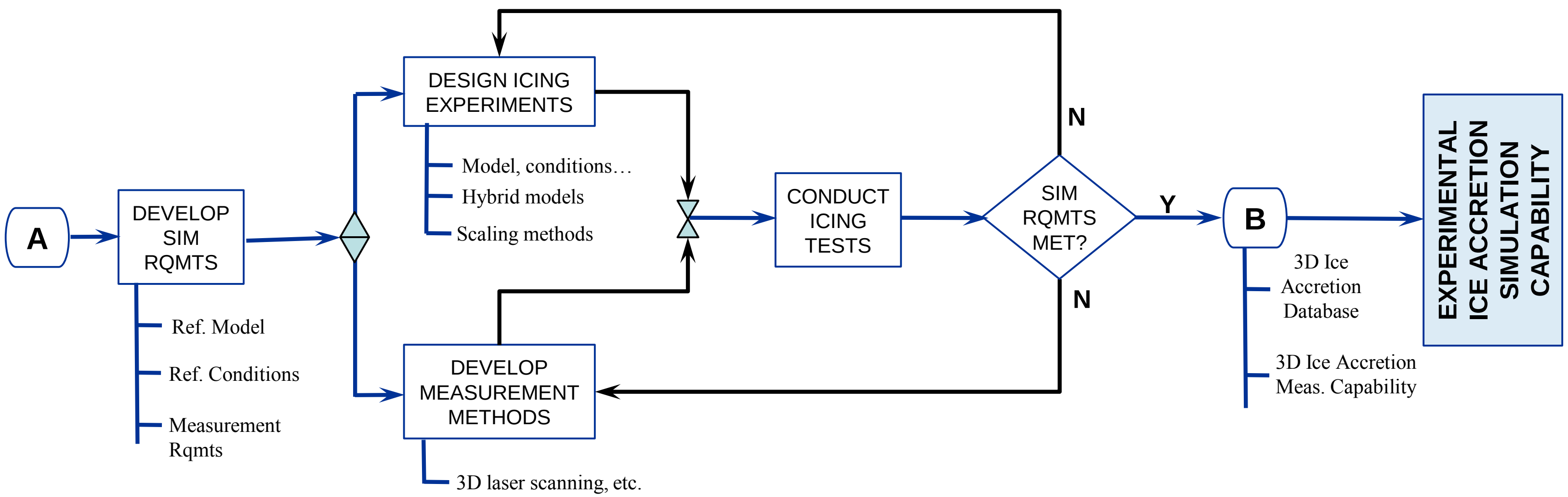
Level	Number	Due Date	Title
2	AEST3.2.17	FY15Q4	Validated Swept Wing Ice Accretion Code (LEWICE3D)
3	AEST3.3.18	FY11Q4	Comprehensive Assessment of Status of 3D Computational Ice Accretion and Aerodynamic Simulation Methods
3	AEST3.3.19	FY14Q3	Improved Swept Wing Icing Physics Models

Computational Ice Accretion Simulation Milestones

Level	Number	Due Date	Title
2	AEST3.2.17	FY15Q4	Validated Swept Wing Ice Accretion Code (LEWICE3D)
3	AEST3.3.18	FY11Q4	Comprehensive Assessment of Status of 3D Computational Ice Accretion and Aerodynamic Simulation Methods
3	AEST3.3.19	FY14Q3	Improved Swept Wing Icing Physics Models

Experimental Ice Accretion Simulation

Technology Development Roadmap



Experimental Ice Accretion Simulation (1/2)

Objective

Develop and demonstrate experimental simulation capability (e.g., icing-tunnel testing) for ice build-up on a 3D aircraft surface such as a swept wing

Research Tasks

- 3D Ice Accretion Measurement Capability
  - Define evaluation/selection criteria and models/ice shapes to be used.
  - Evaluate current laser-scanning systems and conduct further IRT demos if necessary.
  - Down-select one system for further development.
  - 2D Airfoil Model Evaluation:
    - Conduct IRT test with 18-inch chord NACA 23012 model. Laser scans and molds of selected ice accretion.
    - Use scan data to create high-fidelity artificial ice shapes along with castings from molds.
    - Conduct aerodynamic testing and compare results.
    - Perform quantitative geometric comparison between artificial ice shapes.
  - Swept-Wing Model Evaluation
    - Conduct IRT test with swept-wing model. Laser scans and pour molds of selected ice accretion.
    - Use scan data to create high-fidelity artificial ice shapes along with castings from molds.
    - Conduct quantitative geometric comparison between artificial ice shapes.
    - Standardize methods for laser scan data acquisition and post-processing.
      - Write process description with quantifiable standards
  - Declare 3D ice accretion measurement capability

Experimental Ice Accretion Simulation (2/2)

Objective

Develop and demonstrate experimental simulation capability (e.g., icing-tunnel testing) for ice build-up on a 3D aircraft surface such as a swept wing

Research Tasks

- Experimental Ice Accretion Simulation Capability
  - Define reference swept-wing model and reference aerodynamic and icing conditions.
  - Select appropriate 3D CFD tools and evaluate aerodynamics and droplet impingement characteristics in free air for the reference conditions.
  - Design icing experiments by performing 3D CFD analysis including effects of test-section walls.
    - Look at trade-offs in model design such as size vs. effect on impingement.
    - Determine the extent to which local wing conditions (e.g., lift coefficient, collection efficiency, etc.) can be duplicated in the tunnel relative to the reference case.
    - Based upon this outcome, determine if hybrid model designs and/or scaled conditions are needed.
  - Complete swept-wing icing tunnel model conceptual designs.
  - Complete detail design and fabrication.
  - Conduct icing-tunnel testing.
  - Compare aerodynamic (such as surface pressures) results and icing results (such as impingement limits) with CFD predictions.
  - If there are large discrepancies, further research and testing may be required.
  - Otherwise declare capability and conduct further testing to develop initial 3D ice accretion database.

Experimental Ice Accretion Simulation Milestones

Level	Number	Due Date	Title
1	AEST3.1.03	FY13Q4	3D Ice Accretion Measurement Capability
2	AEST3.2.10	FY14Q1	First 3D Ice Accretion Database Obtained
3	AEST3.3.12	FY15Q1	Second 3D Ice Accretion Database Obtained
3	AEST3.3.13	FY12Q1	Select Candidate Laser Scanning System
3	AEST3.3.14	FY13Q4	Deliver Models for Icing-Tunnel Test

Experimental Ice Accretion Simulation Milestones

Level	Number	Due Date	Title
1	AEST3.1.03	FY13Q4	3D Ice Accretion Measurement Capability
2	AEST3.2.10	FY14Q1	First 3D Ice Accretion Database Obtained
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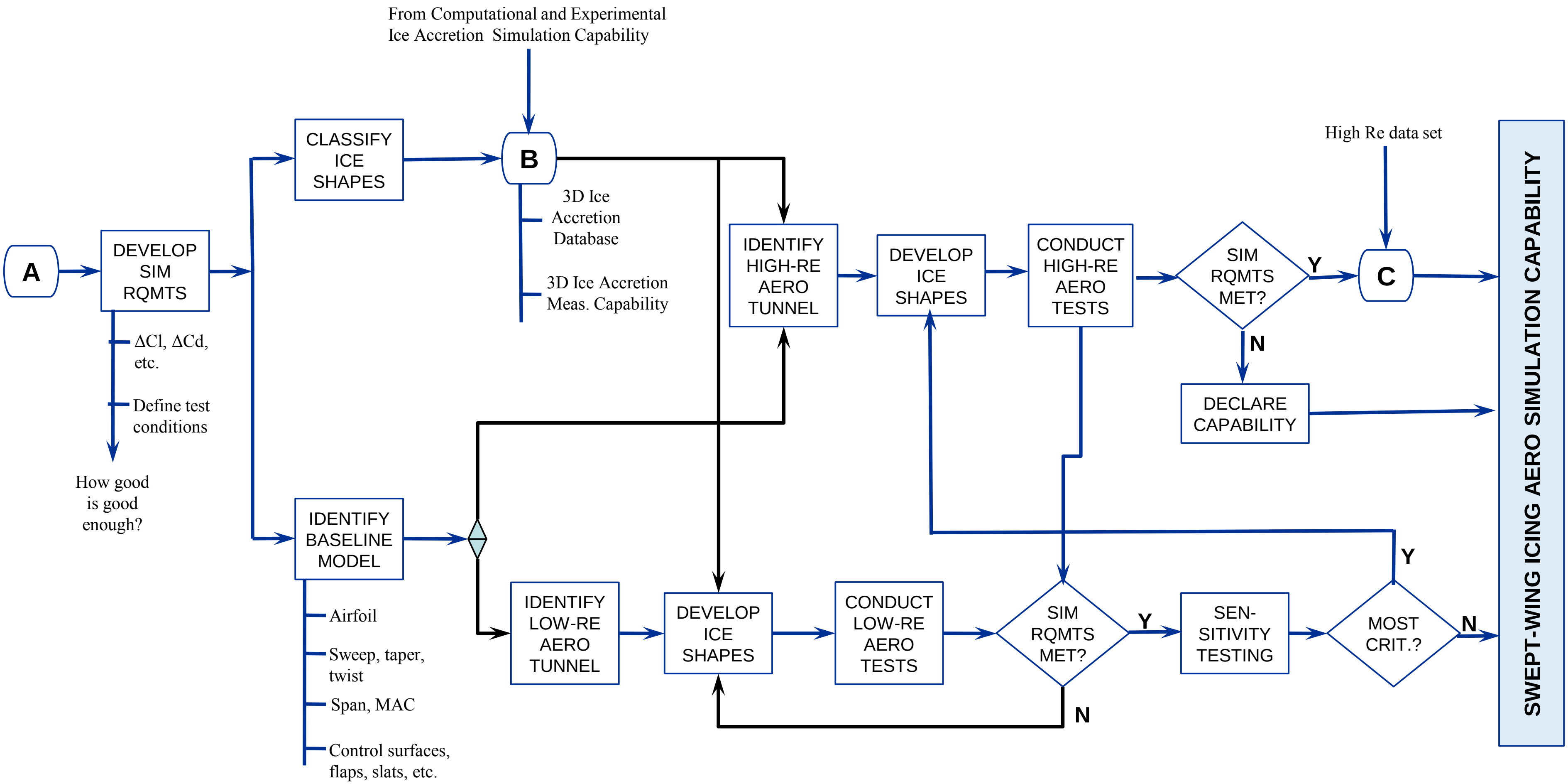
Experimental Aerodynamics Simulation

Technology Development Roadmap



Experimental Aerodynamics Simulation (1/3)

Objective

Develop and demonstrate experimental simulation methods for iced swept wings by quantifying the aerodynamic accuracy associated with geometric fidelity and Reynolds and Mach number effects.

Research Tasks

- Review icing and aerodynamics literature relevant to swept-wing icing.
- Classify ice shapes according to unique iced-wing flowfield features.
- Using the swept-wing reference model identified in the Experimental Ice Accretion Simulation Element conduct model sizing studies for the ONERA F1 wind tunnel.
- Select a low-Reynolds number aerodynamic wind tunnel and conduct model sizing studies.
- Complete F1 model mechanical design and fabrication.
- Complete low-Re model mechanical design and fabrication.
- Design aerodynamic test matrix and define experimental methods.

Experimental Aerodynamics Simulation (2/3)

Objective

Develop and demonstrate experimental simulation methods for iced swept wings by quantifying the aerodynamic accuracy associated with geometric fidelity and Reynolds and Mach number effects.

Research Tasks

- Select ice accretions for aerodynamic testing based upon the ice-shape classifications.
- Design and fabricate artificial ice shapes of the selected ice accretions having varying levels of geometric fidelity.
- Conduct initial low-Re aerodynamic tests to baseline model and ice shape effects.
- Conduct first high-Re test campaign.
- Quantify differences in aerodynamic coefficients between high- and low-Reynolds number testing.
- Conduct ice-shape sensitivity testing to explore range of aerodynamic effects and identify critical configurations.

Experimental Aerodynamics Simulation (3/3)

Objective

Develop and demonstrate experimental simulation methods for iced swept wings by quantifying the aerodynamic accuracy associated with geometric fidelity and Reynolds and Mach number effects.

Research Tasks

- Design and fabricate a second set of artificial ice shapes for the high-Re model based upon the identified critical configurations.
- Conduct second high-Re test campaign.
- Quantify differences in aerodynamic coefficients between high- and low-Reynolds number testing.
- Update the ice-shape classifications developed earlier.
- Quantify the aerodynamic accuracy associated with varying levels of geometric fidelity including Reynolds and Mach number effects.

Experimental Aerodynamic Simulation Milestones

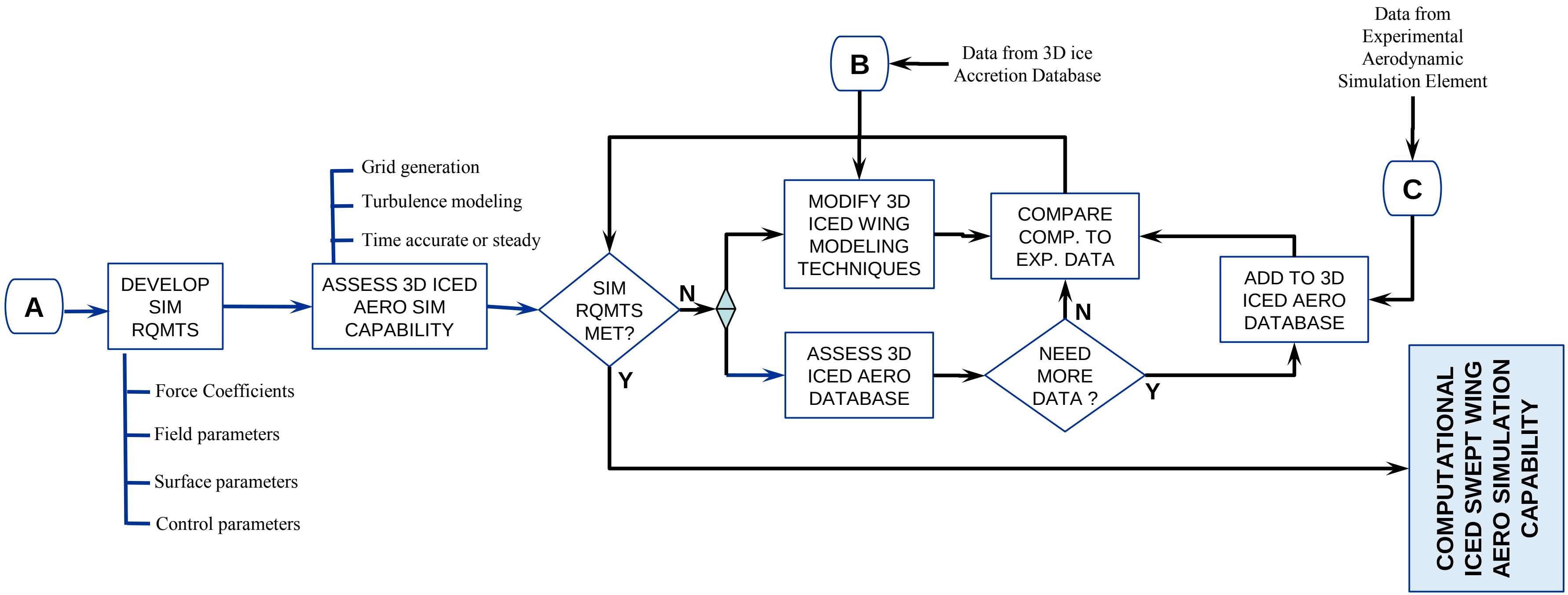
Level	Number	Due Date	Title
2	AEST3.2.9	FY13Q3	CFD Simulation of Low Reynolds Number Swept Wing Aerodynamic Effects
2	AEST3.2.11	FY15Q2	High Reynolds Number Swept Wing Iced Aerodynamic Test
3	AEST3.3.15	FY12Q4	Initial Ice-Shape Classifications
3	AEST3.3.16	FY14Q4	Initial Low-Reynolds Number Aerodynamics Test
3	AEST3.3.17	FY15Q1	High-Reynolds Number Model and Artificial Ice Shapes Delivered

Experimental Aerodynamic Simulation Milestones

Level	Number	Due Date	Title
2	AEST3.2.9	FY13Q3	CFD Simulation of Low Reynolds Number Swept Wing Aerodynamic Effects
2	AEST3.2.11	FY15Q2	High Reynolds Number Swept Wing Iced Aerodynamic Test
3	AEST3.3.15	FY12Q4	Initial Ice-Shape Classifications
3	AEST3.3.16	FY14Q4	Initial Low-Reynolds Number Aerodynamics Test
3	AEST3.3.17	FY15Q1	High-Reynolds Number Model and Artificial Ice Shapes Delivered

Computational Aerodynamic Simulation

Technology Development Roadmap



Computational Aerodynamic Simulation (1/2)

Objective

Develop and demonstrate computational flowfield simulation capability for iced swept wings for aerodynamic performance evaluations.

Research Tasks

- Develop simulation criteria for assessment of CFD methods
- Assess 3D iced aerodynamic simulation capabilities against criteria from existing results in the literature
- Select appropriate methods for CFD simulation effort
  - Ice shape surface geometry modeling fidelity
  - Grid generation strategy
  - Turbulence models
  - Steady or unsteady analysis
- Identify deficiencies is the existing methodologies and recommend alternate practices
- Assess existing 3D iced aerodynamics database for use in this element
- Recommend additional test data that would be required for comparison studies

Computational Aerodynamic Simulation (2/2)

Objective

Develop and demonstrate computational flowfield simulation capability for iced swept wings for aerodynamic performance evaluations.

Research Tasks

- Perform sensitivity studies with existing techniques to assess accuracy of CFD analysis methods
- Based upon sensitivity studies make recommendations for use of current CFD methods for analysis of 3D iced swept wing aerodynamics and for areas of future research on method improvement
- Document CFD accuracy for analysis of iced swept wing configurations

Computational Aerodynamic Simulation Milestones

Level	Number	Due Date	Title
3	AEST3.3.18	FY11Q4	Comprehensive Assessment of Status of 3D Computational Ice Accretion and Aerodynamic Simulation Methods
3	AEST3.3.21	FY13Q4	Computational Studies of Critical Parameters for Accurate Simulation of 3D Ice Shape Aerodynamics
3	AEST3.3.22	FY15Q1	Validated Computational Methods for CFD Analysis of Iced Swept Wing Configurations

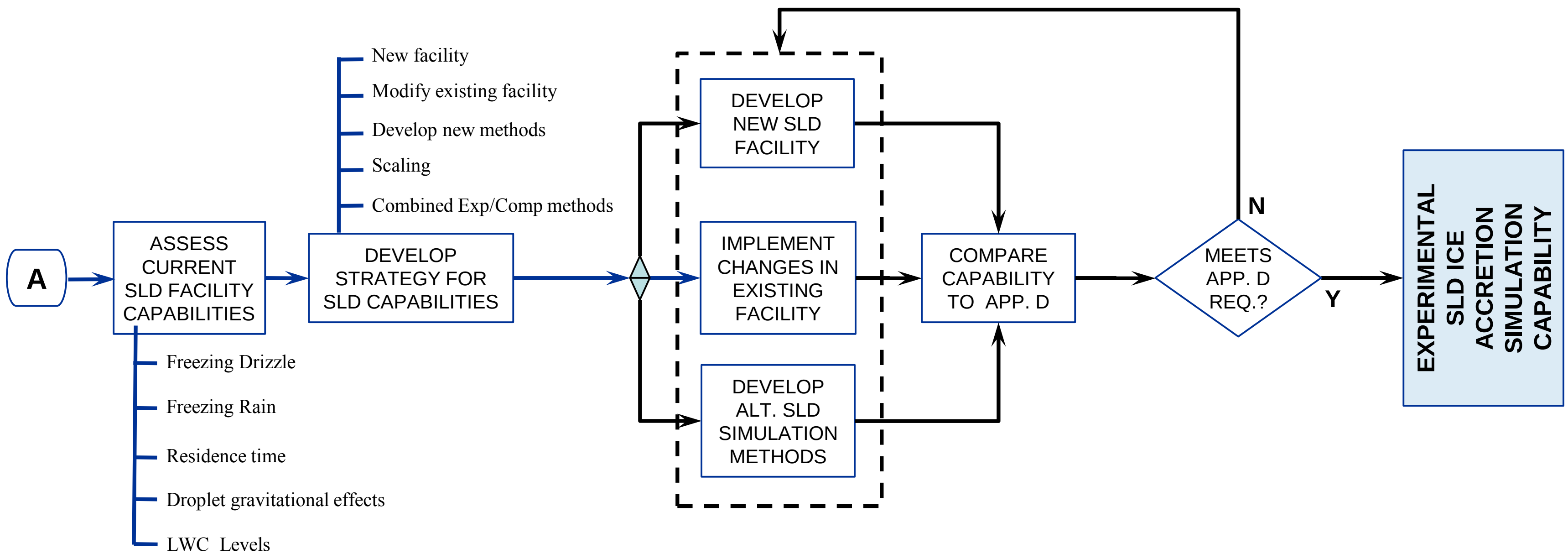
Computational Aerodynamic Simulation Milestones

Level	Number	Due Date	Title
3	AEST3.3.18	FY11Q4	Comprehensive Assessment of Status of 3D Computational Ice Accretion and Aerodynamic Simulation Methods
3	AEST3.3.21	FY13Q4	Computational Studies of Critical Parameters for Accurate Simulation of 3D Ice Shape Aerodynamics
3	AEST3.3.22	FY15Q1	Validated Computational Methods for CFD Analysis of Iced Swept Wing Configurations

SLD Icing Research

Experimental SLD Ice Accretion Simulation

Technology Development Roadmap



Experimental SLD Ice Accretion Simulation

Objective

Develop and demonstrate experimental simulation capability for SLD ice build-up on aircraft surfaces.

Research Tasks

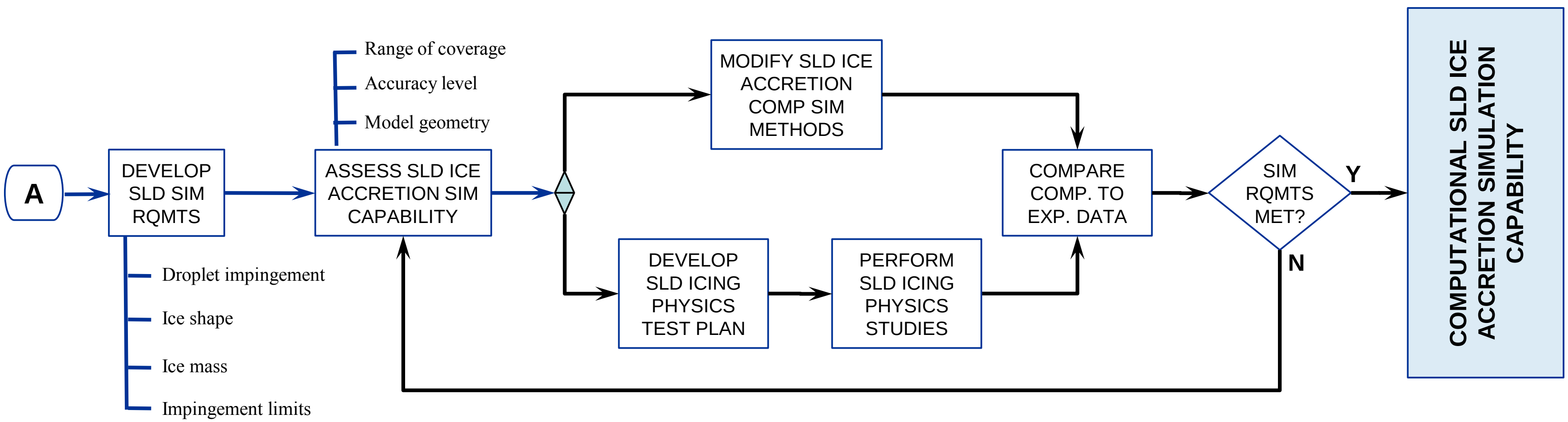
- Assessment of Current Known SLD Simulation Capabilities
  - Identify facilities with known or potential SLD capabilities
  - Identify characteristics required for SLD simulation
  - Compare facility capabilities to requirements
  - Identify gaps in capabilities
  - Recommend strategies for development of SLD experimental simulation capabilities

Experimental SLD Ice Accretion Simulation Milestones

Level	Number	Due Date	Title
2	AEST3.2.7	FY12Q1	Develop a Strategy for Improved SLD Experimental Simulation Capability

Computational SLD Ice Accretion Simulation

Technology Development Roadmap



Computational SLD Ice Accretion Simulation

Objective

- Develop and validate computational simulation capability for SLD ice build-up on aircraft surfaces.

Research Tasks

- Assessment of Computational SLD Simulation Capability
  - Define simulation requirements
  - Assess range of validated SLD computational simulation capabilities
  - Compare capabilities to requirements
  - Develop recommendations for testing and model development
- SLD Icing Physics Studies
  - Develop and implement test programs based upon recommendations from assessment task.
- Computational Model Development for SLD Icing Simulation
  - Based upon assessment task and SLD icing physics studies, develop models for SLD simulation improvements
  - Compare computational results to experimental data
  - Document improvements to ice shape and collection efficiency modeling

Computational SLD Ice Accretion Simulation Milestones

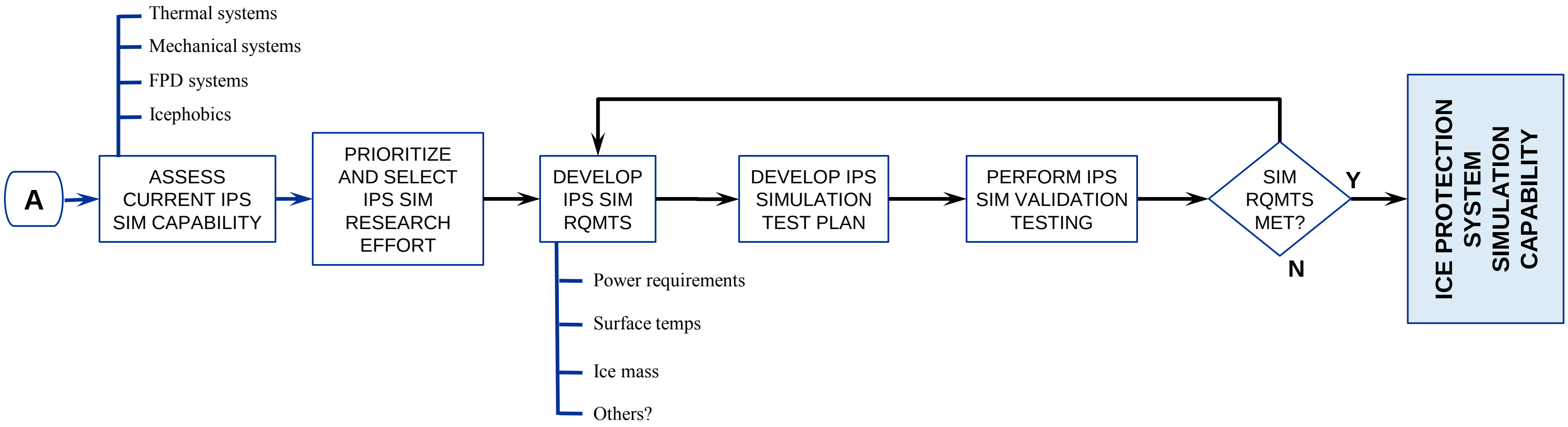
Level	Number	Due Date	Title
2	AEST3.2.8	FY14Q1	Improved Computational Simulation Capability for SLD Icing Conditions
3	AEST3.3.18	FY11Q4	Comprehensive Assessment of Status of 3D Computational Ice Accretion and Aerodynamic Simulation Methods
3	AEST3.3.24	FY13Q3	Improved Icing Physics Models for SLD

Computational SLD Ice Accretion Simulation Milestones

Level	Number	Due Date	Title
2	AEST3.2.8	FY14Q1	Improved Computational Simulation Capability for SLD Icing Conditions
3	AEST3.3.18	FY11Q4	Comprehensive Assessment of Status of 3D Computational Ice Accretion and Aerodynamic Simulation Methods
3	AEST3.3.24	FY13Q3	Improved Icing Physics Models for SLD

Ice Protection System Modeling for SLD

Technology Development Roadmap



Ice Protection System Modeling for SLD

Objective

- Develop techniques that aid in the design and validation of ice protection system simulation methods.

Research Tasks

- Assessment of Current IPS Simulation Methods
  - Identify current ice protection system simulation methods
  - Identify differences between flight conditions and IPS evaluation facilities
  - Assess impact of differences on IPS evaluation efforts
  - Identify gaps in capabilities
  - Recommend strategies for development of IPS experimental simulation methods

Computational SLD Ice Accretion Simulation Milestones

Level	Number	Due Date	Title
3	AEST3.3.26	FY12Q3	Development of an Investment Strategy for Ice Protection System Modeling Methods